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UNDERWATER-APPLIED COATINGS FOR STEEL STRUCTURES

By

Richard W. Drisko

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Several underwater-applied epoxy coatings were developed for protecting steel structures in seawater. The more promising formulations were laboratory and field tested at different times using a brush, a roller, and a curved plastic applicator developed by the Navy Coastal Systems Laboratory. The coating that was the easiest to apply underwater is now marketed by a commercial supplier. Sandblasting was found to be the best method of preparing steel surfaces for painting underwater, and waterblasting was the next best of the five methods tested.

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INTRODUCTION

The Navy has miles of steel waterfront structures situated in very corrosive environments. The protective coatings on these structures are subject to accelerated deterioration both by the environment and by impact and abrasion. While deteriorated coatings in dry areas are relatively easily repaired, those located between tides or underwater have in the past been very difficult, if not impossible, to repair.

In 1962, the Shell Chemical Company offered coating and adhesive manufacturers a two-component epoxy formulation designed to cure on either dry, damp, or underwater surfaces. Shortly thereafter several coating manufacturers began marketing products (generally called splash-zone compounds) that were prepared directly from, or were variations of, this formulation. These products were so viscous that they had to be applied by the palm of the hand at 1/8 to 1/4 inch thicknesses rather than by a brush or roller at the usual paint thicknesses. The Navy investigated [1-9] the use of these products and prepared a specification[a] for them. Because they were difficult and costly to apply, the Civil Engineering Laboratory (CEL) conducted the present investigation into lower viscosity coatings that could be applied underwater by brush or roller.

MATERIALS INVESTIGATED

Most of the commercially available coatings that can be applied by brush underwater have been laboratory-tested by CEL. The vast majority of these have been solvent-free epoxies, but some polyester formulations have been tested. The polyester materials have generally been easier to apply, but they cure much more slowly and tend to be soft and more easily damaged. Because the epoxy coatings have been more durable, this CEL investigation was limited to them. Of the Navy-devised epoxy formulations, those utilizing amine-adducts as curing agents showed the most promise. Two of the more promising basic formulations, 101 and 102, were prepared by a coating supplier in batch quantities. The composition of these formulations is shown in Table 1. Table 2 shows several variations that were made in the curing agent to improve such properties as wetting of substrate (101-19 and 102-19) and rate of curing (101-5 and 102-5).

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[a] MIL-P-28379 (YD), Plastic Compound, Epoxy-Polyamide, Marine Splash-Zone Application.

Table 1. Basic Formulations of Underwater-Applied Paints

Formulation	Part A		Part B	
	Component	By Weight	Component	By Weight
101	Epon 828[a]	42	Epicure 8701[b]	8.7
	Lead Silica Chromate	38	Epicure 874[b]	1.4
	Blown Fish Oil, Z-7-1/2	17	Epon 828[a]	1.9
	Butyl Cellosolve	3		
		100		12.0
102	Epon 828[a]	45	Epicure 8701[b]	8.7
	Lead Silica Chromate	38-1/2	Epicure 874[b]	1.4
	Blown Fish Oil, Z-7-1/2	16-1/2	Epon 828[a]	1.9
		100		12.0

[a] Trade name of Shell Chemical Company.

[b] Trade name of Celanese Resins.

Table 2. Special Variations of Basic Formulations by Changing Part B[a]

Formulation Number	Part B[b] (by weight)	LO[c] (by weight)	DMP-30[d] (by weight)	Tin Biocide[e] (by weight)
101-2	12	6		
102-2	12	6		
101-5	8		5	
102-5	8		5	
101-19	16			5
102-19	16			5

[a] Weights shown in table were used with 100 parts of Part A of either 101 or 102.

[b] Part B of 101 and 102 are identical.

[c] Ancamine LO of Anchor Chemical Company.

[d] 2, 4, 6-Tri (dimethylaminomethyl) phenol.

[e] Reaction product of tributyltin oxide and fatty acids of linseed oil.

LABORATORY TESTING

A laboratory procedure was developed for determining the bonding strength of underwater-applied coatings to steel. A small, 1/8-inch-thick steel panel is sandblasted to white metal.[b] It is then placed in a tank of seawater and brush-coated with an underwater-applied coating. After curing underwater for 1 week, the coated panel is dried and lightly sanded. One or more steel probes are then bonded to the sanded coating using a high-strength, quick-setting adhesive. After the adhesive has cured overnight, the probe is pulled from the panel using a table model Instron testing machine.

The bonding strengths of the six formulations in Table 2, which were applied and cured at the various temperatures indicated, are listed in Table 3. It can be seen from this table that:

(1) The 101-19 formulations were the easiest to apply.

(2) Of the three sets of curing conditions, application and curing at 70°F generally resulted in the greatest bonding strength, and application and curing at 40°F generally resulted in the weakest.

[b] Steel Structures Painting Council Surface Preparation No. 5.

Table 3. Bonding Strengths of Formulations Used at Different Temperatures

Formulation Number	Mixing Temperature (°F)	Application and Curing Temperature (°F)	Bonding Strength (kg/sq cm)	Ease of Application
101-2	70	70	27; 49; 19[a]	good-fair
101-2	70	40	31; 16; 23; 8[a]	fair
101-2	40	40	18; 14; 20[b]	fair
101-5	70	70	53; 31; 19; 48[a]	fair
101-5	70	40	53; 19; 18; 22[a]	fair
101-5	40	40	3; 12; 16; 9[b]	fair
101-19	70	70	32; 23; 7; 24; 29[b]	good
101-19	70	40	14; 15; 25; 8; 11; 12[a]	good
101-19	40	40	13; 11; 5; 10; 7; 7[b]	good[c]
102-2	70	70	25; 36; 22; 40[b]	fair
102-2	70	40	20; 14; 17; 23	fair
102-2	40	40	6; 5; 4; 4[a]	fair
102-5	70	70	25; 31; 63; 26[a]	fair
102-5	70	40	14; 11; 16; 13[d]	fair
102-5	40	40	8; 4; 13; 8[a]	fair
102-19	70	70	27; 32; 37; 19; 14; 23[b]	good
102-19	70	40	9; 4; 9; 6; 3; 12[a]	fair
102-19	40	40	10; 6; 7; 8; 11; 7[d]	fair

[a] Some adhesive failure; some coating failure.

[b] Adhesive bond failed; no bonding failure of coating to steel.

[c] Applied well, but did not level well.

[d] Coating failure only.

Although most of the underwater-applied coating work was conducted with seawater, deionized water and freshwater were also used in one brief test to determine if the paints could be used in these waters at 70°F. Formulation 101-19 was brush-applied to pairs of sandblasted steel panels in tanks of deionized water, tap water, and seawater. In all cases the coating was easily applied. After curing overnight, one panel from each pair was wiped with a cloth saturated with a 50/50 mixture of methylethyl ketone and toluene in order to remove any surface film such as might be formed from amine migration to the surface. These panels were then returned to their respective tanks, and all six panels were topcoated with 101-19. The unwiped panels in the deionized and tap water tanks were noticeably more difficult to coat than the others. After curing underwater for 1 week, the bonding strengths of the paints on each panel were determined as previously described; the results of these tests are shown in Table 4. Although the unwiped panels in the deionized and tap water tanks were more difficult to topcoat, the topcoat bonded as well as or better than the wiped panels.

FIELD SURFACE-PREPARATION TESTS

A small field test was conducted at Port Hueneme on steel panels to determine the effect on bonding strength of different methods of preparing their surfaces for underwater painting. Six sandblasted[c] steel panels (2-3/4 inch by 6 inch) were corroded to a similar degree by exposure for 8 days in a 5% salt spray cabinet. They were then secured in place on a wooden specimen holder (Figure 1) and treated with different methods of surface preparation as follows:

Treatment 1 – Waterblasted above water at 10,000 psi and 10 gpm (Figure 2)

Treatment 2 – Waterblasted underwater at 10,000 psi and 10 gpm (Figure 3)

Treatment 3 – Waterblasted underwater at 8,500 psi and 10 gpm with 16-30 mesh copper slag abrasive injected

Treatment 4 – Manual wirebrushing underwater

Treatment 5 – Sandblasting above water (accepted optimum surface preparation procedure)

Treatment 6 – Uncleaned control

After cleaning, the panels given treatments 1, 2, and 4 had a similar crudely cleaned appearance (Figure 4), while those given Treatments 3 and 5 had a white metal appearance.

---

[c] Steel Structures Painting Council Surface Preparation No. 5.

Table 4. Bonding Strength of Formulation 101-19 in Different Waters

Type of Water	Wiped With Solvent	Bonding Strength (kg/sq cm)
Deionized	yes	14;[a] 16[a]
Deionized	no	21;[a] 28[b]
Tap	yes	10;[a] 34[b]
Tap	no	34;[b] 36[b]
Salt	yes	22;[a] 27[b]
Salt	no	12;[a] 15[a]

[a] No intercoat failure.

[b] Some intercoat failure.

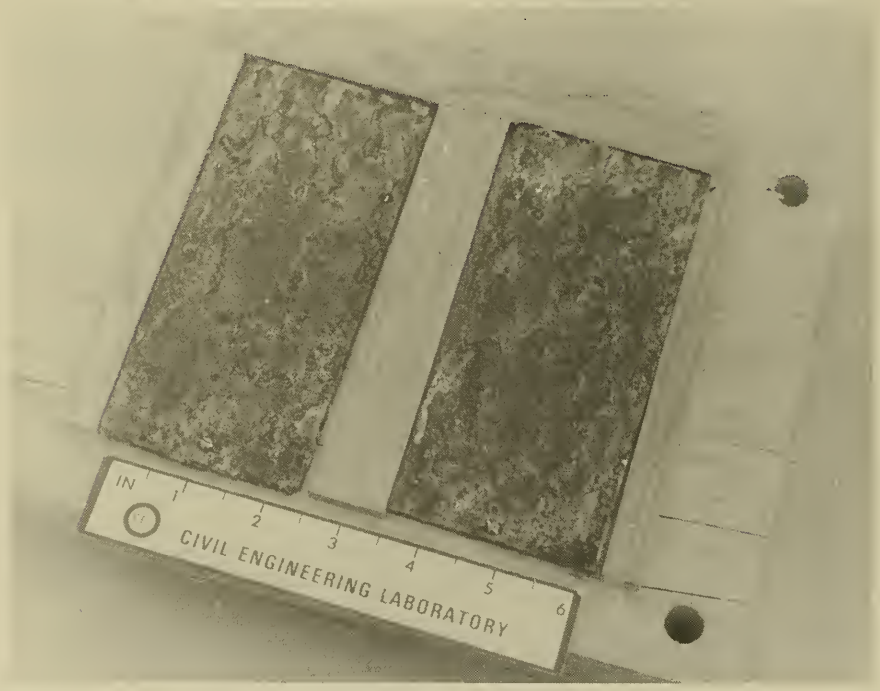

Figure 1. Corroded steel panels in specimen holder.

Figure 2. Waterblasting of steel panels above water (Treatment 1).

Figure 3. Waterblasting of steel panels underwater (Treatment 2).

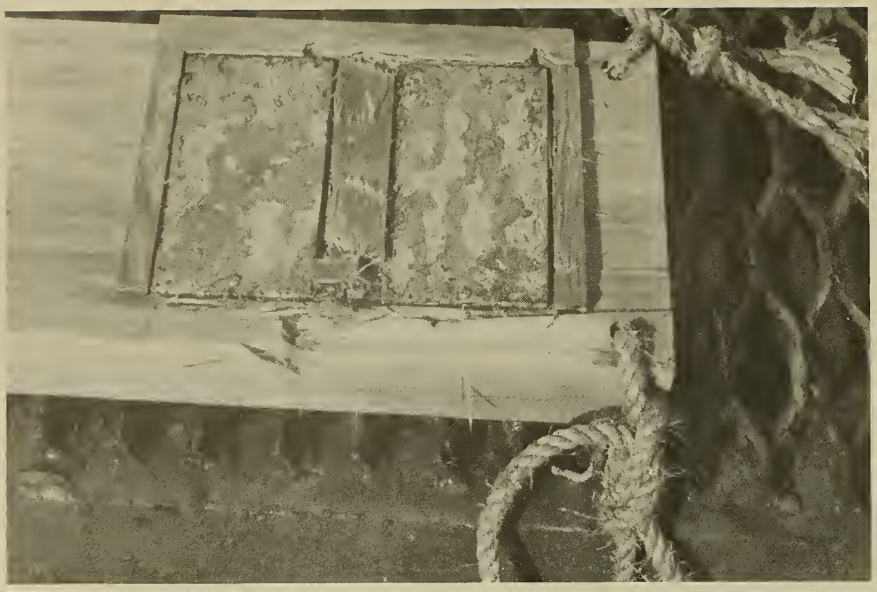

Figure 4. Test panels cleaned by Treatment 1.

Each cleaned panel was brush-coated underwater with CEL Formulation 101-2 and cured underwater for 1 week before the bonding strengths of the coating were determined as previously described. All the panels were coated relatively easily. The results shown in Table 5 indicate that sandblasting (Treatment 5) gave the best bonding strength and waterblasting underwater (Treatment 2) the next best. Waterblasting above water (Treatment 1), waterblasting underwater with added abrasive (Treatment 3), and wirebrushing (Treatment 4) resulted in a much reduced bonding strength, but it was still well above that of the uncleaned control panel (Treatment 6).

FIELD TESTING OF UNDERWATER-APPLIED PAINTS ON QUEEN MARY

With the cooperation of CDR John W. McAdams and Mr. Marvin M. Wolff of the Queen Mary Department of the City of Long Beach, a field test of four CEL formulations was conducted on the Queen Mary on 21 January 1975. These four formulations were 101-2, 102-2, 101-5, and 102-5. The area selected for the test was located partly above and partly below water on the steel propeller box on the port side. It was given only a

Table 5. Bonding Strengths of Formulation 101-2 on Steel Surfaces Cleaned by Different Methods

Treatment Number[a]	Breaking Strength (kg/sq cm)	Method of Failure
1	9; 8	coating
2	18; 17	mostly adhesive
3	10; 6	coating
4	7; 10	coating
5	26; 24	both coating and adhesive
6	3; 9	coating

[a] See text for description of treatments.

cursory cleaning by scraping and wirebrushing to remove loose paint, chalk, and other surface contamination. The four orange paints were applied in 1-foot squares that were easily distinguished from the adjacent red paint. The portions above water were still wet from the rinsing when painted. Application was faster above water and generally smoother. Formulations 101-2 and 102-2 were much easier to apply than 101-5 and 102-5. They all displayed a tendency to sag from a vertical surface when applied above water.

USE OF CEL UNDERWATER-APPLIED PAINT BY PORT OF LONG BEACH

Pier C at the Port of Long Beach had numerous weak areas (about 200) where holes or thin places had occurred in the steel sheet piling. A contract was negotiated with Pacific Marine Enterprises of Seal Beach, California, to cut out these areas and repair them by welding in steel plates. The contract specified coating the oval-shaped plates (about 3 to 6 sq ft in area) with CEL epoxy paint and touching up by brush the weld areas. The procedure used was to roll two coats of formulation 101-19 onto the steel plates to give about 20 mils dry film thickness, weld these plates in place, clean the welds, and apply two coats of paint to them underwater.

FIELD TESTING AT PANAMA CITY

During the week of 10-14 March 1975, a cooperative field test was conducted with the Naval Coastal Systems Laboratory, Panama City, Florida. The test site was located in St. Andrews Bay, an inlet of the Gulf of Mexico. The experiment was conducted on a platform located about 20 feet underwater and about 20 feet from an NCSL pier facility. The temperature of the water was about 65°F (18.3°C). The experiment was conducted to (1) compare ease of application of two underwater-applied formulations with each other under laboratory-controlled conditions, (2) compare ease of application of underwater-applied paints to sandblasted and wirebrushed steel specimens and to vertically and horizontally placed steel specimens, and (3) field test the NCSL-developed coating applicator.

Experimental specimens 2 feet by 2 feet by 1/4 inch were prepared from rusty, mild steel plates either by sandblasting in an NCSL shop prior to immersion or by wirebrushing underwater (Figure 5). The sandblasted finishes were no better than a Steel Structures Painting Council Surface No. 6 (Commercial Blast Cleaned Surface Finish); wirebrushing underwater was accomplished by a diver using a hydraulically powered wirebrush (Figure 6).

The underwater surface preparation and the material applications were accomplished by different two-man teams; in all cases, the team consisted of an NCSL-civilian diver and a military diver. A curved, plastic applicator (Figure 7), designed and fabricated by NCSL, was used to coat the steel specimens. A portion of coating was poured onto the steel and then spread with the applicator.

Experiments on individual specimens (see Figure 8, for example) are described in detail below and then summarized in Table 6 for easy comparison:

Specimen 1. A rusted panel was secured in a horizontal position and wirebrushed underwater. The 101-2 formulation was somewhat difficult to apply underwater with the curved plastic applicator. A metal pressure-feed system (Figure 9) was used with Specimens 1 and 2 to place portions of the coating on the steel before being spread with the applicator. The equipment was quite messy to clean up, so with subsequent specimens the coating was poured directly from the can onto the steel.

Specimen 2. A sandblasted, horizontally held steel panel was coated with some difficulty with the 101-2 formulation. It was a little easier to coat than the Specimen 1 panel.

Specimen 3. A rusted panel was secured in a vertical position and wirebrushed underwater. It was extremely difficult to coat it with the 101-2, and, consequently, only about half of it was coated.

Specimen 4. A sandblasted, vertically held steel panel was coated with extreme difficulty with the 101-2 formulation. It was almost as difficult to apply as with Specimen 3. Consequently, only about three-quarters of it was coated.

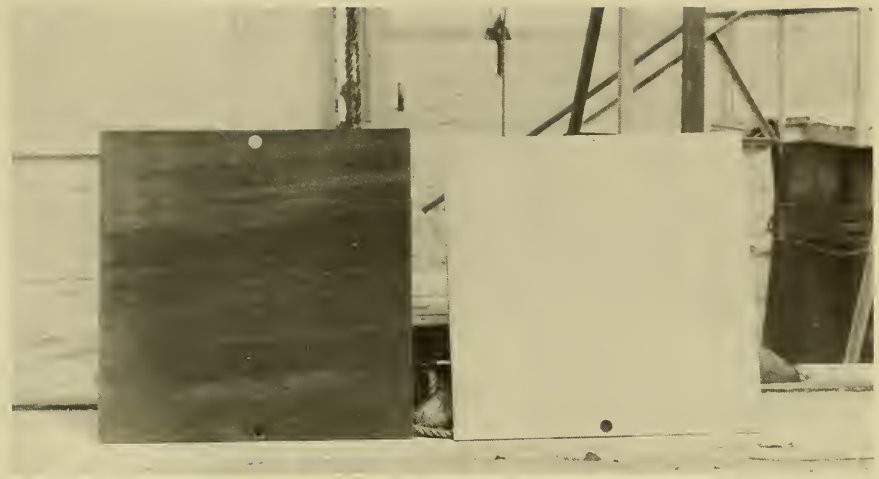

Figure 5. Two test panels; left panel before wirebrushing underwater and right panel after sandblasting.

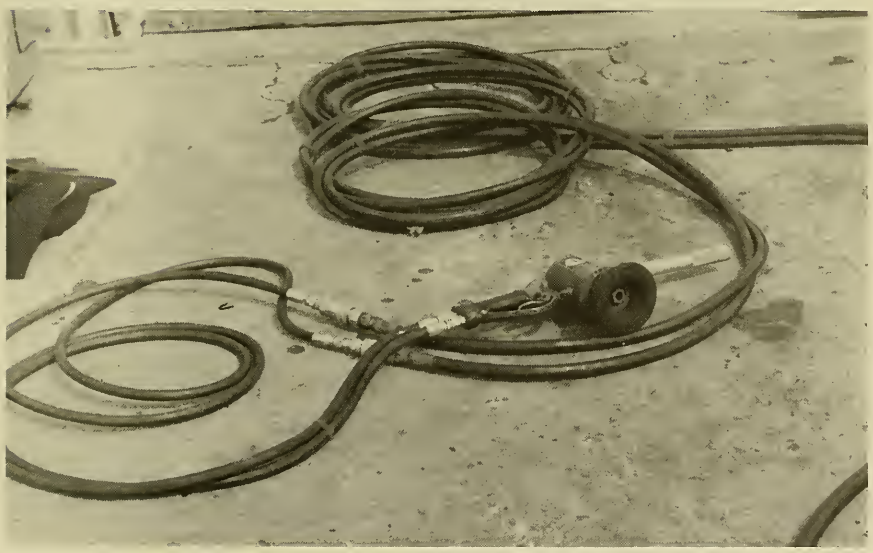

Figure 6. Hydraulically powered wirebrush equipment used for cleaning steel panels underwater.

Figure 7. Curved plastic applicator which was designed and fabricated by NCSL.

Figure 8. Coated test panel after curing underwater overnight.

Table 6. Summary of Underwater Coating Experiments at Panama City

Specimen Number	Formulation	Surface Preparation	Position Held	Application of Paint
1	101-2	wirebrushed	horizontal	difficult
2	101-2	sandblasted	horizontal	difficult
3	101-2	wirebrushed	vertical	extremely difficult
4	101-2	sandblasted	vertical	extremely difficult
5	101-19	wirebrushed	horizontal	easy
6	101-19	sandblasted	horizontal	easy
7	101-19	sandblasted	vertical	easy
8	101-19	wirebrushed	vertical	easy
9	101-19	sandblasted	vertical	easy

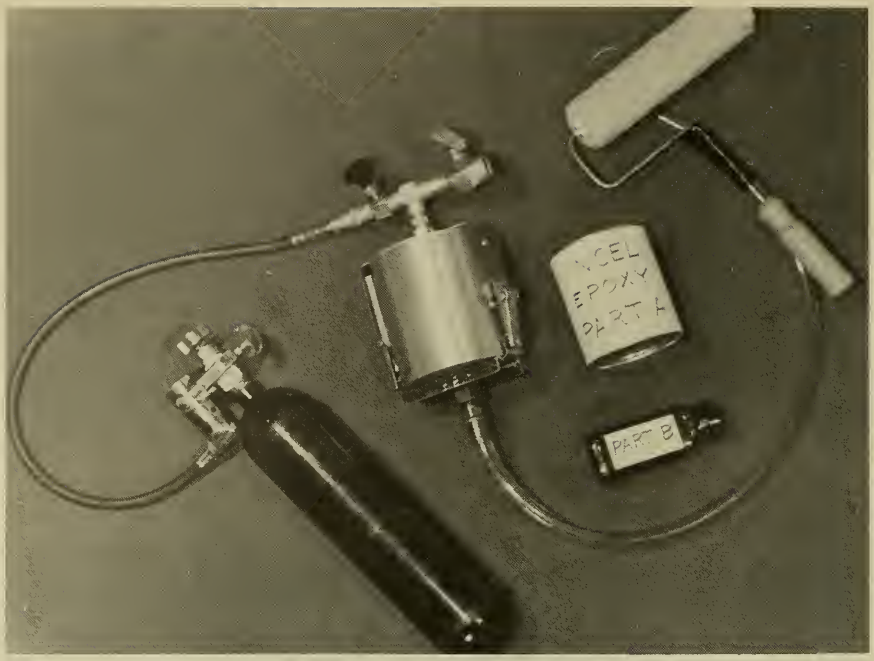

Figure 9. Equipment for supplying paint directly to test specimen using compressed air from a cylinder. (The pictured roller was not used in the field test.)

Specimen 5. A rusted panel was secured in a horizontal position and wirebrushed underwater. The 101-19 formulation was easily applied to the steel panel. A little cratering of the paint (contraction to expose bare metal) occurred, but the paint was readily spread back over such areas.

Specimen 6. A sandblasted, horizontally held steel panel was easily coated with the 101-19 formulation. As with Specimen 5, there was some cratering, but this was no problem.

Specimen 7. This specimen was coated similar to Specimen 6, except that the panel was held in a vertical position. Again the paint was easily applied, and some small cratering was noted. On the following day, this specimen was given a second coat of the 101-19 formulation, which was also easily applied.

Specimens 8 and 9. These were wirebrushed and sandblasted specimens, respectively, which were held in a vertical position. Both were easily coated with the 101-19 formulation.

From the testing at Panama City it was found that:

1. The steel, pressurized equipment for supplying paint to the surface of the substrate or applicator is extremely difficult and costly to clean for reuse. A system with a collapsible, disposable plastic bag for a reservoir would be much more practical.

2. Whenever paint application problems are encountered, a sandblasted surface is somewhat easier to coat than a wirebrushed surface, and a horizontal surface is somewhat easier to coat than a vertical surface.

3. CEL formulation 101-19 is an easily applied, versatile product that can effectively coat underwater-sandblasted or -wirebrushed steel surfaces in both horizontal and vertical positions. It can be applied as a topcoat to itself.

4. The NCSL underwater paint applicator can be effectively used to apply 101-19, but it may not presently be in its most effective form.

SUMMARY

From the laboratory and field testing, it was determined that Formulation 101-19 was the most practical of those tested. It is available commercially for use by the Navy or private industry. The choice of a brush, roller, or curved plastic applicator varies with the individual diver and the job. The roller and plastic applicator are best used on large, flat surfaces, while the brush can be used on any type of surface. A relatively stiff, round brush appears to be especially effective. Sandblasting was the most effective of the five surface preparation systems tested; waterblasting was the next best.

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